14.—Potassium-argon ages of hornblendes from Precambrian gneisses from the south coast of Western Australia

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Abstract

Potassium-argon ages obtained from hornblendes from seven samples of amphibolite and basic granulite from three localities in the gneiss-granite complex of the south coast of Western Australia range from 1060 to 1160 m.y., with no detectable differences between localities. These results show good agreement with the Rb-Sr isochron age of 1100 ± 50 m.y. previously obtained from the Albany Adamellite. This could suggest that the K-Ar hornblende ages reflect the period of late-kinematic emplacement of anatectic granitic plutons (represented by the Albany Adamellite) which is believed to have occurred during waning metamorphism. Alternatively, they could be regarded as indicating the age of late-orogenic regional uplift and cooling. These are not necessarily conflicting interpretations because it is possible that late-kinematic emplacement of granitic magmas and regional uplift were roughly synchronous events. About 1150 m.y. can be regarded at present as only a minimum estimate of the age of high-grade regional metamorphism in the south coast area.

Introduction

Precambrian gneisses and granitic plutons outcrop along the south coast of Western Australia between Point D'Entrecasteaux and Israelite Bay, a distance of roughly 750 km. This area forms part of the Albany-Fraser Province, a narrow arcuate belt wrapped around the southern and southeastern margins of the Archaean Yilgarn Block. This belt appears to represent the site of a younger Precambrian orogenic belt that cut across the Archaean shield (Wilson 1969).

A general account of the geology of the region has been given by Clarke *et al.* (1954). The gneisses are predominantly granitic in character, with intercalated metasedimentary and metabasite bands; migmatitic types are common. The metamorphic grade varies from upper amphibolite to lower granulite facies, with the higher-grade rocks occurring as large enclaves scattered through the amphibolite facies terrain. The gneisses have been intruded by numerous porphyritic coarse-grained granitic plutons, cut in turn by fine-grained granitic dykes and, later, by occasional dolerite dykes. Stephenson (1973*a*, *b*, 1974) believes that the granitic plutons and dykes have been derived from the gneissic country rocks by anatexis during orogeny and high-grade regional metamorphism, and that emplacement and crystallisation occurred during waning metamorphism under syn- to late-kinematic conditions.

The geochronology of the south coast area has not been adequately investigated. Turek and Stephenson (1966) reported a microcline-total-rock Rb-Sr isochron age of 1100 ± 50 m.y. for one of the granitic plutons (the Albany Adamellite) but there may, of course, have been more than one episode of granitic magma emplacement. The main phase of high-grade regional metamorphism responsible for the gneisses is thought to have preceded the emplacement of granitic plutons, but it has not been reliably dated. The only published radiometric data on these gneisses are a chemical U-Pb age (uncorrected for Pb isotopes) of 1390 ± 50 m.y. given by allanite from pegmatitic schlieren in charnockitic gneiss from Doubtful Island Bay (Prider 1954), and a Rb-Sr age of 970 m.y. given by biotite from gneiss from the same locality (Wilson *et al.* 1960). The significance of these dates is not yet fully understood, but the latter is clearly only a minimum estimate of the age of the main metamorphism.

The geochronology of the northeastern part of the Albany-Fraser Province (i.e. in the vicinity of the Fraser Range) is better known and possibly of some significance to the south coast region. Compston and Arriens (1968) and Arriens and Lambert (1969) reported a total-rock Rb-Sr isochron of 1330 ± 15 m.y., which is interpreted as a reliable estimate of the age of an episode of granulite facies metamorphism in this area. Preliminary data presented by Arriens and Lambert (1969) and Bunting *et al.* (1976) suggest that gneisses and granites flanking the 1330 m.y.-old granulites were formed during an earlier metamorphism around 1600-1900 m.y. ago. A period of retrogression and pegmatite emplacement during uplift and waning metamorphism about 1280-1290 m.y. ago is suggested by a Rb-Sr age of 1280 m.y. obtained by Aldrich *et al.* (1959) on muscovite from one of the numerous small pegmatites in the 1300 m.y.-old granulites, and by a Rb-Sr total-rock isochron age of 1289 ± 21 m.y. given by muscovite-bearing gneisses and pegmatites associated with gneisses possibly 1900 m.y. old (Bunting *et al.*, 1976). In view of the structural continuity between the south coast and Fraser Range areas (Doepel 1969) it is likely that they experienced regional metamorphism at least broadly contemporaneously. Furthermore, it seems reasonable to suppose that the history of metamorphism of the south coast gneisses was possibly as long and complex as it appears to have been in the Fraser Range area.

The purpose of this paper is to report and interpret K-Ar ages obtained from hornblendes separated from seven samples of amphibolite and basic granulite from three localities in the gneissic complex along the south coast. Two of these samples are from Albany near the Albany Adamellite, two from Forsyth Bluff near the Torbay Adamellite, and three from Cape Riche where there are no known granitic plutons. These localities are shown in Figure 1, and short petrographic descriptions of the samples are given in the Appendix. It was hoped that a comparison of the ages of the Albany and Forsyth Bluff samples, which are expected to reflect the period of granitic magma emplacement, with those obtained from the Cape Riche samples would clarify the temporal relations between high-grade metamorphism and granitic magma emplacement in the south coast area. It is realised that the scope of this investigation is far too limited to provide a detailed geochronological analysis of the possibly complex metamorphic history of the region.

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Methods

Hornblende was separated from the washed −120 to +200 mesh fractions of the crushed rock samples using a Frantz isodynamic separator followed by repeated centrifuging in heavy liquids. The purity of the final separates was better than 99%.

The methods used in the K-Ar age determinations have been described by McDougall (1966). Potassium was determined by flame photometry. Argon measurements were carried out in the Isotope Geology Laboratory at the University of Queensland using the isotope dilution technique, following fusion of the sample and extraction of argon in a high vacuum line. After purification of the gas the isotopic composition was determined on an A.E.I.G.E.C.—MS20 mass spectrometer. The constants used in the calculations were: $\lambda_e = 0.585 \times 10^{-10}$ yr^{-1}; $\lambda\beta = 4.72 \times 10^{-10}$ yr^{-1}; $^{40}K/K = 0.000119$. Errors were calculated using the method of Kirsten (1966). The results are listed in Table 1.

Discussion of results

Table 1 shows that the measured ages range from 1060 to 1160 m.y., with no detectable differences between the three sample localities.

Samples R36265 and R36266 were collected from basic granulite bands in the gneiss within the granitised zone around the Albany Adamel-

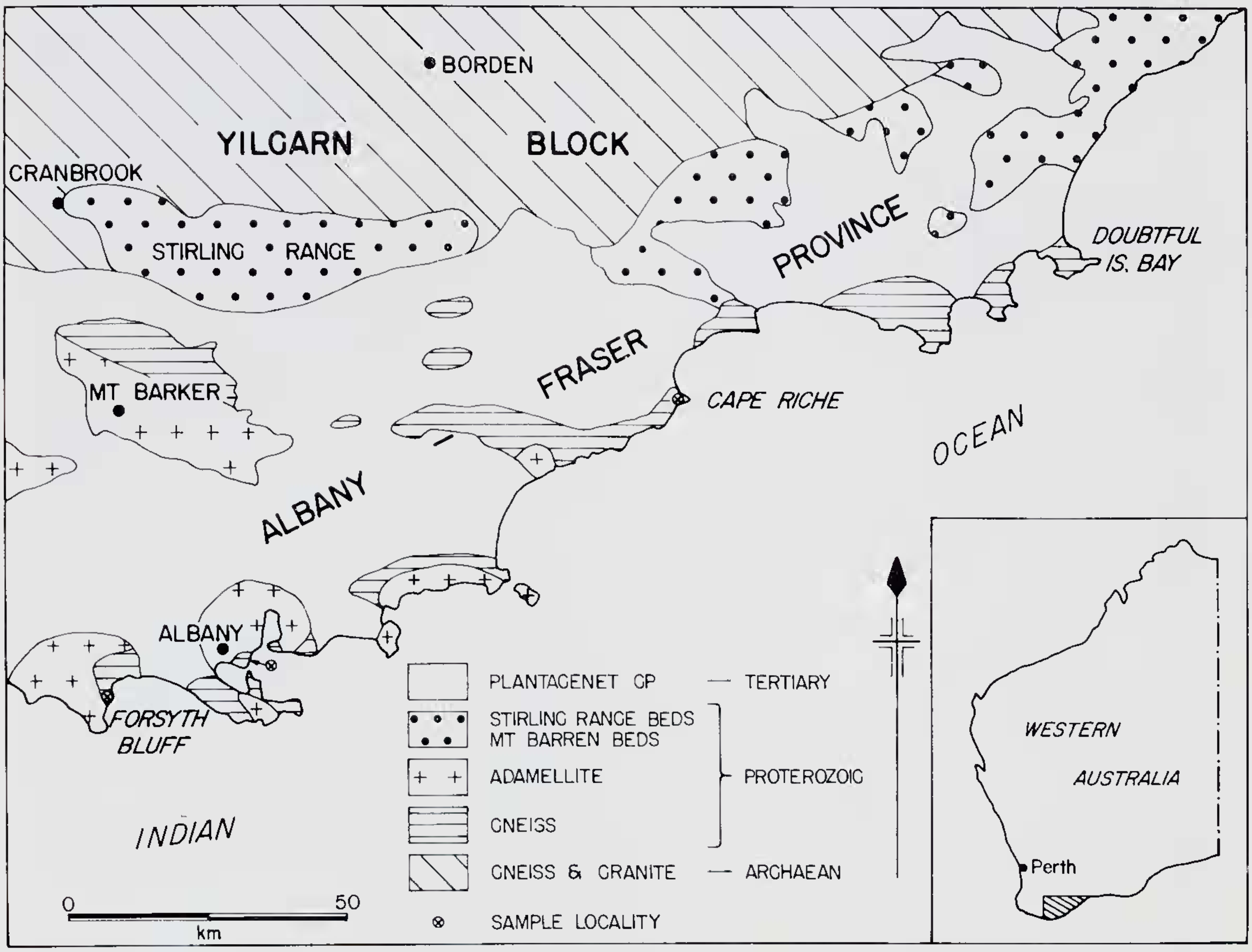

Figure 1.—Geological map of part of the south coast of Western Australia showing the sample localities at Forsyth Bluff, Albany, and Cape Riche. (Based on the Geological Map of Western Australia compiled by the Geological Survey of Western Australia, 1973. Modifications by N. C. N. Stephenson.)

Table 1

K-Ar ages on hornblendes from amphibolites and basic granulites from the south coast of Western Australia

Sample No.*	QA No.†	Rock Type	K %	Rad. ^{40}Ar %	Age (m.y.)	Error‡ (m.y.)	Latitude (south)	Longitude (east)	Locality
54563	267	Amphibolite	0·71	29·71 §	1059	±51	35°05·1′	117°38·6′	Forsyth Bluff
65581	273	Amphibolite	1·04	99·75	1151	±15	35°05·1′	117°38·7′	Forsyth Bluff
R36265	268	Granulite	1·13	97·57	1156	±24	35°01·8′	117°55·1′	King Point, Albany
R36266	269	Granulite	1·04	34·86 §	1103	±31	35°01·5′	117°55·1′	Ellen Cove, Albany
R36269	270	Granulite	1·38	98·64	1133	±24	34°36·5′	118°46·3′	Cape Riche
R36270	271	Granulite	1·45	99·49	1153	±24	34°36·5′	118°46·3′	Cape Riche
R36271	272	Granulite	1·41	97·86	1066	±18	34°36·2′	118°46·2′	Cape Riche

$\lambda_\epsilon = 0\cdot585 \times 10^{-10}\ \text{yr}^{-1}$ $\lambda_\beta = 4\cdot72 \times 10^{-10}\ \text{yr}^{-1}$ ^{40}K/K = 0·000119

* Numbers prefixed by R refer to the collection of the Geology Department, University of New England. The remainder refer to the collection of the Geology Department, University of Western Australia.

† University of Queensland, Isotope Laboratory catalogue number.

‡ Errors calculated using the method described by Kirsten (1966).

§ The low values of radiogenic argon percentages are due to a malfunction in the pumping system and they are reflected in the rather large error. For a discussion of the effect of atmospheric contamination see Cox & Dalrymple (1967).

lite. The rocks within this zone show extensive metasomatic enrichment in Si and K, and partial retrogression to amphibolite facies assemblages, presumably due to the introduction of hydrous fluids from the adamellite magma (Stephenson 1974). Both samples contain a little orthoclase and quartz of probable metasomatic origin (see Appendix), and there seems little possibility that they escaped the thermal influence of the pluton. The ages obtained from these samples (1156 ± 24 and 1103 ± 31 m.y.) show good agreement with the Rb-Sr isochron age of 1100 ± 50 m.y. obtained by Turek and Stephenson (1966) for the Albany Adamellite, and they therefore seem to reflect the episode of magma emplacement.

Samples 54563 and 65581 are from amphibolite bands outcropping 800 m and 1 400 m respectively from the southeastern margin of the Torbay Adamellite. Neither sample shows obvious thermal or metasomatic effects attributable to the pluton, but 54563 lies within the zone of appreciable Si and K metasomatism, and 65581 is from the perimeter of this zone. Hence the age obtained for 54563 (1059 ± 51 m.y.) is likely to reflect the emplacement of the Torbay Adamellite. This pluton has not been dated but it shows late-kinematic characteristics similar (though less obvious) to those of the Albany Adamellite (Stephenson 1974), so it is tentatively believed to be of comparable age; i.e. roughly 1100 m.y. The age given by 65581 (1151 ± 15 m.y.), though older, may also have been influenced by emplacement of the Torbay Adamellite, and hence it provides only a minimum estimate of the age of high-grade regional metamorphism.

The significance of the results obtained from the Cape Riche samples is not entirely clear. Although there are no known granitic plutons in the area, the dates obtained from these samples—namely 1133, 1155, and 1066 m.y.—are not detectably older than the inferred age of granitic magma emplacement. Hence the data have failed to demonstrate that the phase of high-grade regional metamorphism in the south coast area occurred significantly earlier than the emplacement of granitic magmas represented by the Albany Adamellite. However this is a possibility that still cannot be ruled out because the dates obtained from the Cape Riche samples could reflect any of several events in the orogenic cycle following the most intense phase of metamorphism. For example, the emplacement of large masses of granitic magma about 1100 m.y. ago may have been caused by, or given rise to, a period of regional reheating detectable by K-Ar dating even in areas remote from these plutons. The minor retrograde effects which appear to be ubiquitous in granulite facies areas of the south coast should also be considered. The Cape Riche samples from which the hornblendes were separated for dating were chosen for their relative freedom from these effects, but incipient alteration is nevertheless evident in their orthopyroxenes and plagioclases (see Appendix). Although the hornblendes show no visible signs of alteration the dates obtained from them could reflect this minor retrogression. Another possible interpretation of the predominance of Rb-Sr and K-Ar dates around 1100-1150 m.y. obtained from the intrusive and gneissic rocks is that they represent the phase of regional uplift and cooling during the final stages of the orogenic cycle in the south coast area. Even in hornblende, a relatively retentive mineral (e.g. Dalrymple and Lanphere 1969, p. 174), diffusion loss of radiogenic argon does not cease until cooling has reached a temperature a few hundred degrees below the temperature of upper amphibolite to lower granulite facies metamorphism to which these rocks have been subjected. Therefore it is unlikely that K-Ar dating will record the age of the most intense phase of metamorphism unless cooling was particularly rapid.

The K-Ar ages reported above show an interesting correlation with the total-rock Rb-Sr isochron age of 1150 ± 40 m.y. obtained by Turek and Stephenson (1966) from slates and phyllites from the nearby Stirling Range Beds, and this merits brief discussion. The Stirling Range Beds, together with the Mt Barren Beds to the east, form an east-west-trending strip of Precambrian low-grade metasediments outcropping discontinuously along the junction between the Albany-Fraser Province and the Yilgarn Block in the south coast area (Fig. 1).

Contact relations are not well exposed but the low-grade metasediments appear to overlie the gneiss-granite complexes of the Albany-Fraser Province and the Yilgarn Block with a faulted unconformity (Sofoulis 1958*a, b*). The Stirling Range and Mt Barren Beds exhibit structures interpreted by several observers as indicating thrusting from the south; either thrusting of the metasediments themselves towards and over the adjacent Yilgarn Block, or overthrusting of the metasediments by the gneiss-granite complex of the Albany-Fraser Province, or a combination of both (Wilson 1952; Clarke *et al.* 1954; Sofoulis 1958*a, b*). It seems likely that these thrusting movements may have been associated with uplift of the Albany-Fraser Province in the south coast area. Clarke *et al.* (1954) indicated that the low-grade metamorphism of the Stirling Range Beds was associated with the thrusting described above, and Turek and Stephenson (1966) interpreted the 1150 m.y. Rb-Sr isochron obtained by them from slates and phyllites from the Stirling Range Beds as the age of this metamorphism and thrusting. If this low-grade metamorphism and thrusting was associated with uplift of the Albany-Fraser Province as suggested above, then this uplift occurred roughly 1150 m.y. ago. This is consistent with the suggestion that the 1060-1160 m.y. K-Ar ages reported in this paper reflect mainly the post-metamorphic regional uplift and cooling of the gneiss-granite complex of the south coast area. This conclusion does not necessarily conflict with the alternative suggestions that late-kinematic emplacement of granitic magmas or widespread incipient retrogression, or both, have influenced the recorded ages because it is not improbable that these events were roughly synchronous with regional uplift. In any case, about 1150 m.y. can probably be regarded at present as only a minimum estimate of the age of regional metamorphism in the south coast area. Because it seems likely that this region has had a long and complex history of deformation, metamorphism, and granitic magma emplacement yet to be unravelled, further structural, petrological, and geochronological studies should prove rewarding.

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Appendix—Petrography

Samples 54563 and 65581: Amphibolites

These are fine- to medium-grained equigranular rocks composed of hornblende (roughly 50%) with X = pale yellowish brown, Y = yellowish green, Z = green, andesine (40%) showing patchy saussuritisation, and biotite (10%). Quartz, magnetite, sphene, apatite, and zircon are minor accessories. The texture is predominantly granoblastic-polygonal, modified by a vague preferred orientation of biotite and hornblende producing a weak foliation.

Samples R36265 and R36266: Basic granulites

These are fine- to medium-grained granoblastic-textured rocks containing andesine (roughly 40%), hornblende (30%) (X = light brown, Y = brown, Z = dark green), orthopyroxene (10%), biotite (5%), perthitic orthoclase (5%), quartz (5%), and (in R36266 only) clinopyroxene (5%). Opaque oxide, apatite, and zircon are minor constituents. Orthoclase and quartz occur as irregularly distributed poikiloblasts up to 4 mm in diameter which corrode and enclose the other minerals suggesting metasomatic introduction. In R36265 some of the hornblende and biotite also occurs as poikiloblasts enclosing pyroxene, plagioclase, and opaque oxide. In both samples plagioclase forms occasional porphyroblasts relatively free of inclusions. Orthopyroxene shows incipient alteration to fibrous green amphibole and minor chlorite along fractures and grain boundaries.

Samples R36269, R36270, and R36271: Basic granulites

These are medium-grained equigranular rocks composed of andesine (roughly 50%), hornblende (25%) (X = light brown, Y = brown, Z = brownish green), orthopyroxene (15%), clinopyroxene (5%), and biotite (5%). Quartz and orthoclase are additional minor constituents of R36269. Opaque oxide, apatite, and zircon are minor accessories. Orthopyroxene shows slight alteration to green amphibole and rare chlorite along fractures and grain boundaries. Plagioclase in R36270 and R36271 shows incipient alteration to chlorite, calcite, and sericite. The texture is granoblastic-polygonal. A faint mineralogical banding is evident in R36269.
